

ASCA ATLAS OF THE CLUSTER TEMPERATURES

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Abstract

We use *ASCA* data to obtain two-dimensional maps of the gas temperature in three clusters: A754, A3558 and Triangulum Australis (the maps of A2256, A2319, A2163 and A665, also presented at the conference, have since appeared in [5]). All clusters from our sample show considerable temperature decline with radius at $r \sim 0.5\text{--}1\ h^{-1}\text{ Mpc}$, most prominently in distant A2163 and A665. The three clusters presented here also feature asymmetric spatial temperature variations, which may be naturally attributed to the effects of a subcluster merger. As an example, we show that the Triangulum Australis gas temperature and density maps indicate recent nonadiabatic heating, presumably by merger shocks. Unlike most of the clusters, the systems in our sample lack cooling flows (with the possible exception of a weak one in A3558), thus we may be probing the younger members of the cluster population.

Spatially resolved measurements of the gas temperature in clusters of galaxies can provide valuable information on the dynamical history of these systems, pointing to those clusters with recent or ongoing merger activity (e.g., [8]). The present-day cluster merger rate is dependent on cosmological parameters, with more mergers in higher- Ω models. Simulations show that cluster radial temperature profiles are also sensitive to the underlying cosmology (e.g., [2]). Thus, measurements of the cluster temperature structure are of significant interest. Such measurements for hot (and therefore massive) clusters have become possible now with the advent of *ASCA*.

ASCA temperature maps of A2256, A2319, A2163 and A665 were presented in [5] (see also [1]). In this paper, we present our results for A754, A3558 and Triangulum Australis (all three have $z \simeq 0.05$). To reconstruct their temperatures, we employed the technique described in [5,6], using *ROSAT* images as a brightness template and modeling *ASCA* mirror scattering, modifying the technique for the cD region in A3558 [7].

Earlier, *ROSAT* PSPC data suggested the existence of gas temperature variations over the face of A754 [4]. The cluster galaxy distribution and its X-ray image indicate the ongoing subcluster merger, and the temperature nonuniformity supports this hypothesis. Our GIS+SIS results for A754, presented in Fig. 1 (and in more detail in [3]), are in general agreement with earlier findings while having a much better accuracy. We detect a spur of hot gas along the cluster elongation axis. Cooler gas resides in the north-eastern outskirts, and, according to [4], in the region of the brightness peak. The temperature and brightness maps of A754 are strikingly similar to the results of a simulation of a merger with the nonzero impact parameter [2]. If the analogy with the simulation is correct, the eastern and western subunits seen in the image are infalling from North and South, respectively. The elongated plume of cool gas near the X-ray brightness peak is then the stripped atmosphere, and perhaps even a cooling flow, belonged to the eastern subunit.

A3558 is a core member of the Shapley supercluster. Its X-ray image suggests that

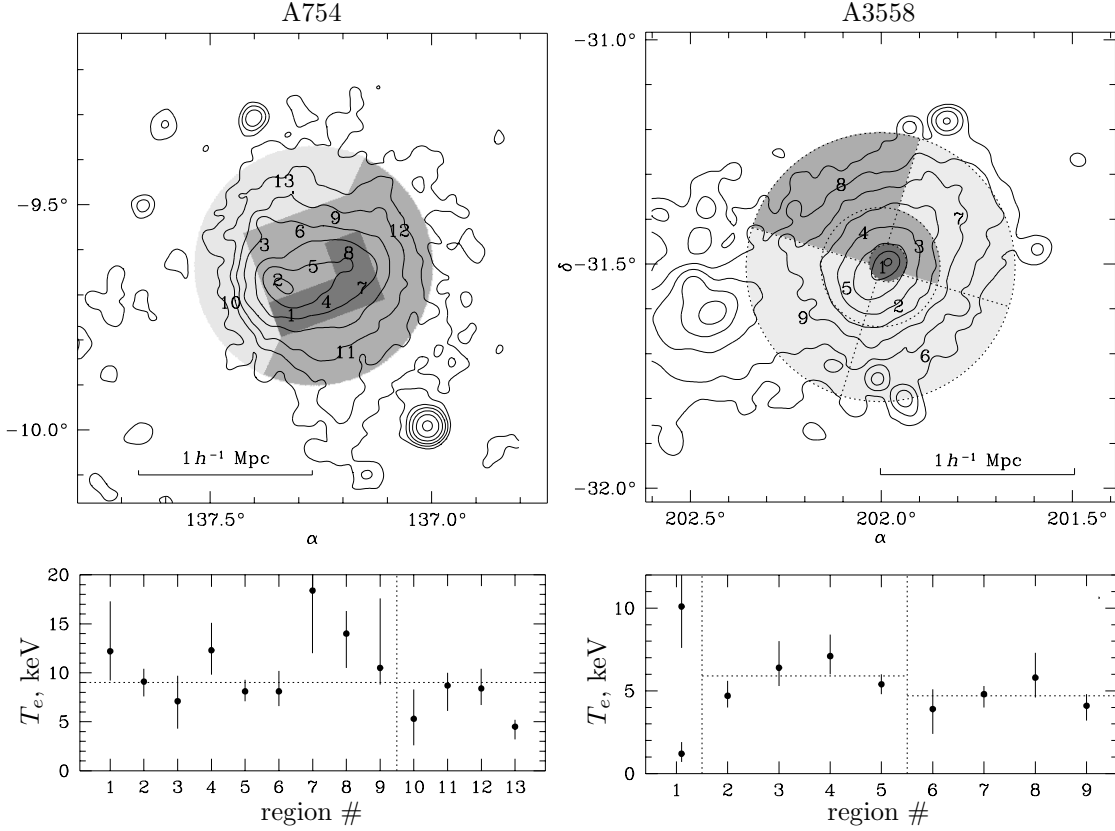


Fig. 1—Temperature maps of A754 and A3558. Contours show *ROSAT* PSPC surface brightness; grayscale shows *ASCA* temperatures. For A754, regions are $5'$ boxes and sectors of the $r = 16'$ circle. For A3558, the regions are an $r = 2.5'$ circle centered on the cD galaxy and sectors of the two annuli $r = 8 - 18'$ around the cluster centroid. Regions are numbered and their temperatures are shown in the lower panels. Two spectral components are shown for the cD region in A3558. Horizontal lines correspond to the average temperature in A754 and average temperatures within each annulus for A3558. All errors are 90%.

the cluster may have experienced a merger and more are to happen. The temperature map and radial profile of A3558 are shown in Figs. 1 and 3. A fit to the cD galaxy region required at least two spectral components, with the additional hot thermal component preferred over a physically meaningful power law [7]. There is a slight radial temperature decline, which is asymmetric. The asymmetry is present in both SIS and GIS data fitted separately, although with marginal significance. We interpret this asymmetry as a merger signature.

A *ROSAT* image of the Triangulum Australis cluster shows that there is an underdense region east of center (Fig. 2; region 2). From the image alone, one expects this region to have a higher temperature to maintain a pressure similar to the adjoining sectors, assuming the cluster gravitational potential is reasonably smooth. Our temperature map indicates that the cluster core has a higher temperature, and the temperature in the low-brightness sector is indeed slightly higher than the average at that radius, just enough to balance the gas pressure. However, its specific entropy, which is a useful diagnostic of shock heating or any other nonadiabatic heating, is significantly higher than that in other regions at the same radius (Fig. 2). The entropy in the core is also higher than that expected in an isothermal model, which is a kind of distribution a cluster gas is expected to approach if left to itself, particularly if thermal conduction is effective. The simplest explanation of such pressure and entropy distribution would be that the gas in

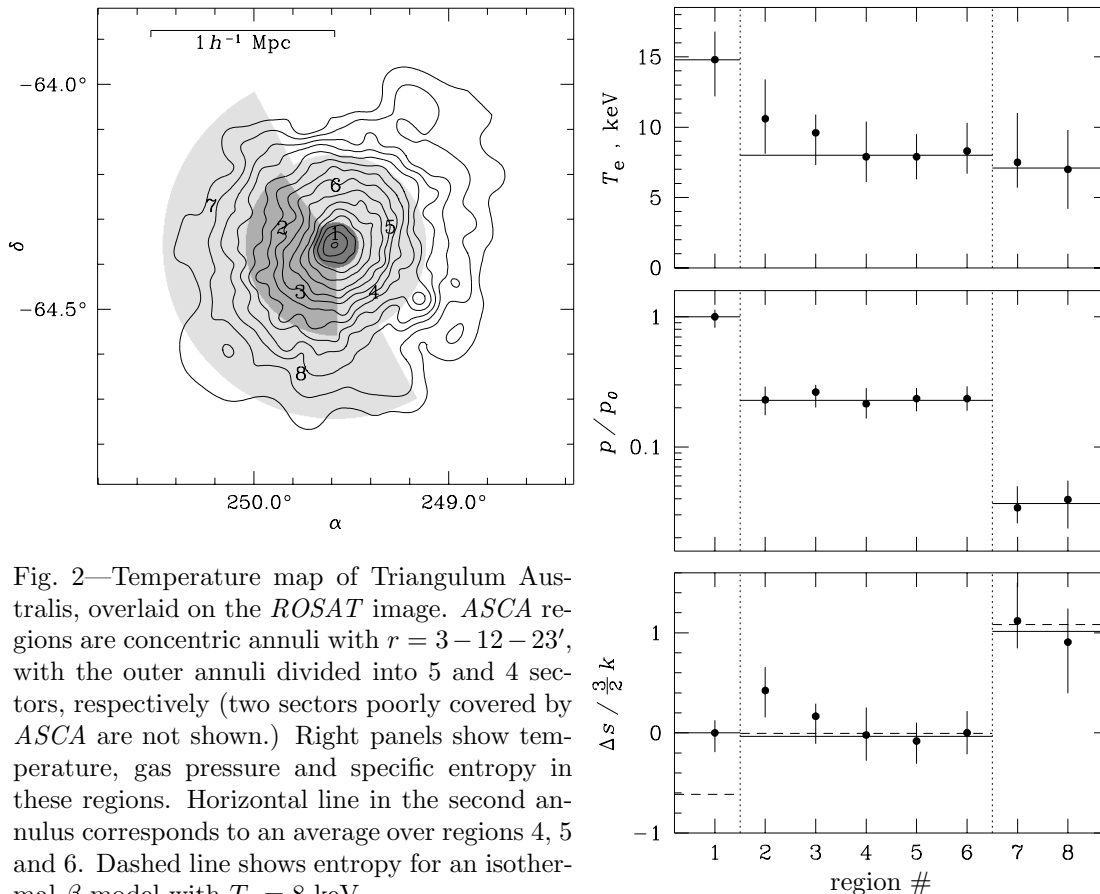


Fig. 2—Temperature map of Triangulum Australis, overlaid on the *ROSAT* image. *ASCA* regions are concentric annuli with $r = 3 - 12 - 23'$, with the outer annuli divided into 5 and 4 sectors, respectively (two sectors poorly covered by *ASCA* are not shown.) Right panels show temperature, gas pressure and specific entropy in these regions. Horizontal line in the second annulus corresponds to an average over regions 4, 5 and 6. Dashed line shows entropy for an isothermal β -model with $T_e = 8 \text{ keV}$.

the cluster center was heated by the passage of a merger shock. The same event might have heated and ejected the gas in region 2 from the center, which then adiabatically expanded to its present density. Hydrodynamic simulations of a head-on merger [8] predict a hot core and an asymmetric temperature structure not unlike the observed one.

Of the eight clusters for which the temperature was reconstructed so far using our method, all but one exhibit a radial temperature drop at $r \sim 0.5 - 1 h^{-1} \text{ Mpc}$ (the exception is nearby AWM7, for which our analysis covered only $r < 0.25 h^{-1} \text{ Mpc}$ and resulted in a constant profile [7]). Fig. 3 shows the radial temperature profiles of those clusters which are relatively symmetric. Of the five clusters reasonably well resolved by *ASCA* (A2256, A2319, A754, A3558 and Triangulum Australis), three, presented here, show asymmetric temperature structure suggestive of a recent or ongoing merger. The other two, A2256 and A2319, although not showing the characteristic temperature asymmetries [5], are probably starting to merge with the subunits which are apparent in their X-ray images, but the process may have not yet disturbed the bulk of gas.

An eventual drop of the gas temperature at some distance from the cluster center is expected intuitively and is predicted by simulations (e.g., [2]). However, in the clusters we studied, the temperature appears to decline even steeper than expected in the standard cosmological models. The most extreme case of A2163 is discussed in [6]. Generally, steeper temperature profiles are predicted in either the models with low Ω (due to the steeper density profiles), or in the models with significant galaxy feedback [2]. In open models, present-day

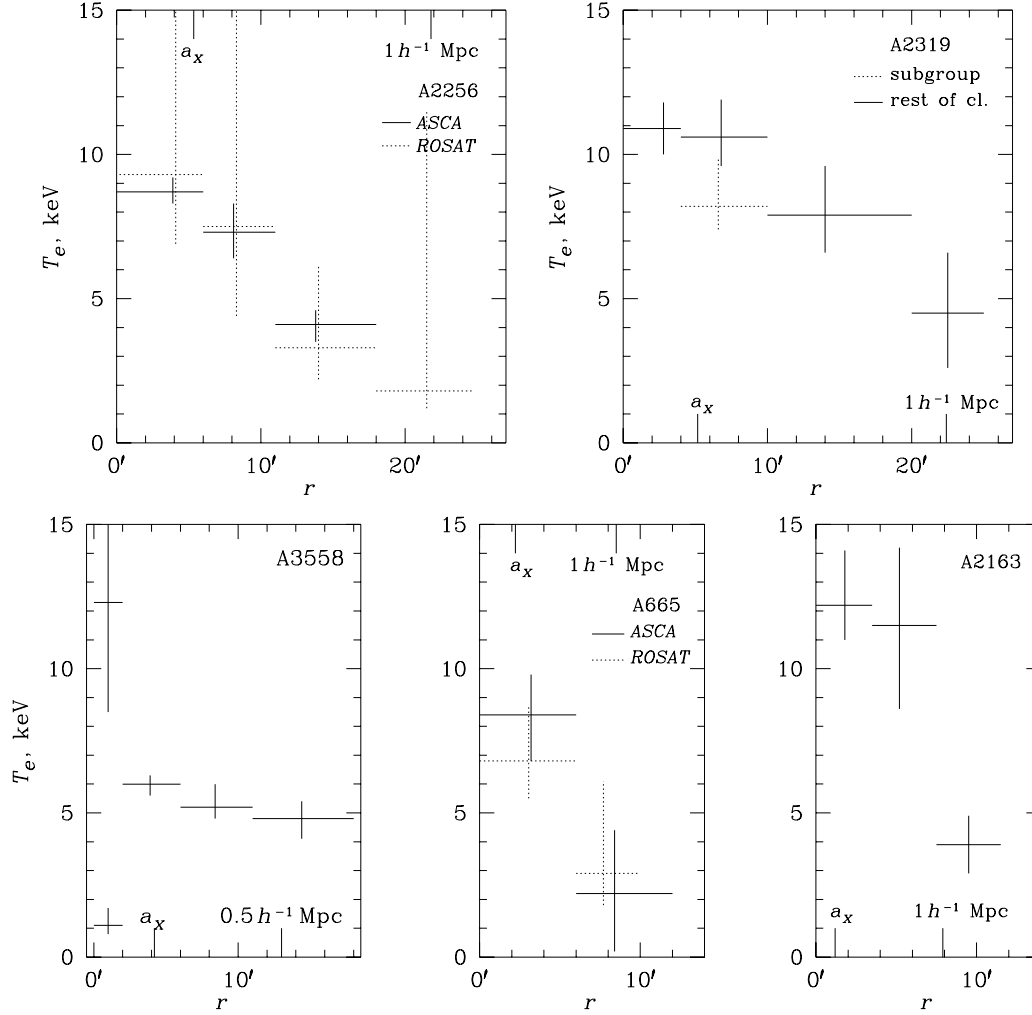


Fig. 3—Radial temperature profiles of five clusters. For A2163, temperatures in three-dimensional shells are shown (from [6]), while other temperatures are projected on the image plane. For A2256 and A665, also shown are *ROSAT* PSPC results from [5,7].

clusters are relaxed and there are few mergers among them.

However, our cluster sample is quite likely to be biased towards younger systems, because of our selection of objects without cooling flows to minimize the effects of the uncertain *ASCA* PSF. Cooling flows may be disrupted by mergers, and merging clusters are expected to have peaked temperature profiles [8]. As our sample expands and becomes more representative, it may become possible to derive cosmological constraints from it.

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